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28JUL03 E825854-1 C78956
P01/7700 0.00-0317604.7

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1. Your reference: SP2021

2. Patent application number *(The Patent Office will fill in this part)*: 28 JUL 2003 **0317604.7**

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

Southampton Photonics Ltd
Phi House
Enterprise Road
Chilworth Science Park
Southampton
SO16 7NS

07894330002
Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation UK.

4. Title of the invention

Apparatus for Material Processing

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Graham Jones & Company
77 Beaconsfield Road
Blackheath
London
SE3 7LG

7.51/77
dd 28/7/04.

Patents ADP number *(if you know it)* 2097001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
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Continuation sheets of this form	
Description	10
Claim(s)	4
Abstract	
Drawing(s)	4 only

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Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
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Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature MPVal Date 28 July 2003

12. Name and daytime telephone number of person to contact in the United Kingdom MP VARNHAM 02380 765417

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Apparatus for Material Processing

Field of Invention

This invention relates to an apparatus for material processing. The invention has particular relevance for welding, drilling and cutting applications using lasers in factory environments in which scatter from ceilings and other surfaces represents a safety hazard, and for low heat generation in high-power fibre lasers.

Background to the Invention

Fibre lasers are increasingly being used for materials processing applications such as welding, cutting and marking. Their advantages include high efficiency, robustness and high beam quality. Examples include femtosecond lasers for multiphoton processing such as the imaging of biological tissues, Q-switched lasers for machining applications, and high-power continuous-wave lasers.

Traditional lasers used for material processing applications predominate at around 1.06μm and longer wavelengths such as provided by a carbon dioxide laser (10.6μm). These lasers are being supplemented by fibre lasers operating at around 1.06μm. Light scattered from the work piece when using such fibre lasers is a problem because the scatter is at wavelengths at which the retina of the eye can be easily damaged.

It is of interest to have eye safe wavelengths for scatter light considerations. This means wavelengths longer than 1400nm, and preferably between 1500nm and 2500nm.

It is also of interest to improve the efficiency of fibre lasers so as to reduce the problem of heat generation within a high power fibre laser. The main source of heat generation is due to the quantum defect (ie the difference in photon energy between

the pump and the laser photons). This means that the pump and laser wavelengths should be as close together as possible.

It is also preferable to use silica fibre because of its heat resistance, low loss properties, and the fact that it can be spliced.

An aim of the present invention is to provide an apparatus for material processing that reduces the above aforementioned problem.

Summary of the Invention

According to a non-limiting embodiment of the present invention, there is provided apparatus for material processing which apparatus comprises a pump for providing pump radiation at a pump wavelength, and an optical fibre doped with rare earth dopant, characterised in that the rare earth dopant emits optical radiation at a signal wavelength in excess of 1400nm when pumped by the pump radiation.

Scatter is often reflected from materials while they are being drilled or welded, and this scatter can be reflected from a factory ceiling. It is therefore advantageous from a safety perspective if the optical radiation is at eye safe wavelengths, and in particular in excess of 1400nm, and preferably between 1500nm and 2500nm.

The apparatus may be such that the pump radiation in-band pumps the rare earth dopant.

In-band pumping is advantageous because it can be used to reduce the heat dissipation with the optical fibre. This is because much of the heat generated arises from the so-called quantum defect, which is related to the difference between the pump wavelength and the wavelength of the optical radiation, the greater the difference, the more heat being generated. By in-band pumping, it is possible to

minimise the difference between the pump wavelength and the wavelength of the optical radiation, thus reducing the heat generated.

Both the pump wavelength and the signal wavelength may be between 1480nm and 2200nm, a feature that is advantageous for eye safety, especially in the event of a fibre break.

The pump may comprise a broad stripe laser diode. The broad stripe laser diode may be optically coupled to the optical fibre. The broad stripe laser diode may be configured to pump a laser. The laser may be a fibre pump laser which may be single mode or multimode.

The apparatus may comprise a pump fibre connecting the pump to the optical fibre. The pump may be located remotely from the optical fibre.

The rare earth dopant may be selected from the group comprising erbium, holmium and thulium. The rare earth dopant may be co-doped with ytterbium.

The rare-earth dopant may be pumped substantially at the peak of its absorption band.

The optical fibre may include a core, and the pump radiation may be coupled to the core.

The optical fibre may comprise a core, a first cladding and a second cladding, the refractive index of the core being greater than the refractive index of the first cladding, the refractive index of the first cladding being greater than the refractive index of the second cladding, and in which the pump radiation is coupled to the first cladding. The rare earth dopant may be located in at least one of the core and the first cladding. The rare earth dopant may be located in a ring around the centre of the core.

The second cladding may comprise a glass or a polymer. The second cladding may be solid or may contain longitudinally extending holes.

The first cladding may be solid. The first cladding may comprise longitudinally extending holes.

In an embodiment of the invention, there is provided apparatus for material processing comprising at least one laser diode for providing pump radiation at a pump wavelength, an optical fibre having a core, a first cladding and a second cladding, which optical fibre is doped with rare earth dopant which when pumped at the pump wavelength emits optical radiation at a wavelength in excess of 1400nm, CHARACTERISED IN THAT the pump wavelength is selected to in-band pump the rare-earth dopant, the laser diode is a broad stripe laser diode, and the pump radiation is coupled into the inner cladding.

In an of the preceding embodiments, the optical radiation may be coupled to a scanner.

The apparatus may include a modulator. The modulator may be an optical switch. The modulator may control the output power from the pump.

The apparatus may include a controller and a modulator, in which the modulator modulates the optical radiation from the optical fibre, and the controller controls the modulation in synchronism with the scanner.

The apparatus may be in the form of a Q-switched laser.

The apparatus may include a seed laser, the apparatus being in the form of a master oscillator power amplifier. The apparatus may include a control circuit to shape the optical radiation to a desired temporal characteristic.

Brief Description of the Drawings

Embodiments of the invention will now be described solely by way of example and with reference to the accompanying drawings in which:

Figure 1 shows an apparatus for providing optical radiation according to the present invention;

Figure 2 shows the spectral absorption of an erbium doped fibre;

Figure 3 shows the spectral emission from an erbium doped fibre;

Figure 4 shows apparatus containing fibre Bragg gratings;

Figure 5 shows apparatus comprising pump modules;

Figure 6 shows apparatus comprising a fibre pump laser;

Figures 7 to 9 show examples of double clad fibres;

Figure 10 shows an example of a holey fibre;

Figure 11 shows apparatus comprising a Q-switched laser;

Figure 12 shows apparatus in which the electrical current powering the laser modules is modulated; and

Figure 13 shows apparatus comprising a master oscillator power amplifier.

Detailed Description of Preferred Embodiments of the Invention

With reference to Figure 1, there is provided apparatus for material processing which apparatus comprises a pump 1 for providing pump radiation 2 at a pump wavelength λ_p 3, and an optical fibre 4 doped with rare earth dopant 5, characterised in that the rare earth dopant 5 emits optical radiation 6 at a signal wavelength λ_s 7 in excess of 1400nm when pumped by the pump radiation 2. The fibre 4 is shown as having a core 8 and a first cladding 9.

Figure 2 shows the absorption 20 as a function of wavelength 21 for an erbium doped fibre. Figure 3 shows the corresponding fluorescence 31 versus wavelength 21. Erbium doped amplifiers as used in telecommunication systems are generally pumped by laser diodes having wavelengths of either 980nm or 1480nm. High power amplifiers and lasers containing erbium are generally pumped at 980nm, or at 915nm if the fibre is co-doped with ytterbium. However these wavelengths are not ideal for high-power lasers including high-power lasers for material processing applications.

Figure 4 shows apparatus in the form of a fibre laser 40 in which the rare earth dopant 5 is in-band pumped. For erbium doping, this means that the pump wavelength the pump wavelength λ_p 3 should be between 1400nm and 1600nm. The fibre laser 40 also comprises a first reflector 41 and a second reflector 42 which form the laser cavity 43. The first and second reflectors 41, 42 are preferably fibre Bragg gratings, although dichroic mirrors, mirrors, or reflectors can be used. Preferably, the first and second reflectors 41, 42 set the signal wavelength λ_s 7, for example by selecting an apropriate reflection wavelength for a fibre Bragg grating. It is desirable that the signal wavelength λ_s 7 is close (within 15nm, but preferably within 5nm) to the pump wavelength λ_p 2. Preferably the pump wavelength λ_p 2 is near the peak of the absorption curve 20. For erbium, this means that the pump wavelength λ_p 2 should be around 1530nm, and certainly within a range of 1525nm to 1535nm. Advantages of the laser 40 include efficient pump absorption (which reduces the length of the optical fibre 4), reduction in thermal effects within the optical fibre 4 by reducing the wavelength difference between pump wavelength λ_p 2 and signal wavelength λ_s 7, and that both the pump wavelength λ_p 2 and the signal wavelength λ_s 7 can be configured at eye safe wavelengths. The advantages combine to give a

laser 40 that is very suited for materials processing applications where the control of thermal dissipation near the work piece and the eye safe wavelengths provide excellent safety advantages over existing systems.

Although the description pertaining to Figures 2 to 3 concentrate on erbium, the rare earth dopant 5 may be selected from the group comprising erbium, holmium and thulium. By appropriate selection of these rare earth dopants, it is possible to set the pump and signal wavelengths 2, 7 within the range 1400nm to 2500nm. This feature is advantageous for eye safety, especially in the event of a fibre break in a factory environment.

The rare earth dopant 5 may be co-doped with ytterbium. This has been found to be advantageous for erbium ytterbium doping when utilizing in-band pumping even though the ytterbium has no spectroscopic function. The ytterbium appears to increase the efficiency of the erbium, possibly by improving its solubility. Ytterbium codoping also appears to avoid other deleterious effects such as clustering which can give rise to up conversion.

Figure 5 shows apparatus in which the pump 1 is a pump module 59 that comprises a plurality of laser diodes 51, fibres 52 and a combiner 53. The pump radiation 2 is coupled via the fibres 52 and the combiner 53 to the optical fibre 4 via an optional pump fibre 54. The laser diodes 51 can be broad stripe laser diodes. Alternatively or in addition, at least some of the laser diodes 51 can be diode bars or diode stacks. The combiner 53 can be a lens or a fused taper coupler such as described in United States patent US 5864644, which is hereby incorporated herein by reference. The pump fibre 54 may be a high numerical aperture multimode optical fibre. The apparatus also comprises focussing optics 55 which focuses the optical radiation 6 via a scanner 56 into a spot 57 on a work piece 58. An advantage of using

the pump fibre 54 is that the pump 1 can be located remotely from the optical fibre 4, for example in a service area within a factory floor. The configuration shown in Figure 5 is suited to the use of 1530nm broad stripe laser diodes for pumping erbium within the optical fibre 4.

Figure 6 shows apparatus in which pump modules 59 pump a fibre pump laser 61. The fibre pump laser 61 in-band pumps the optical fibre 4. The fibre pump laser 61 comprises a rare-earth doped fibre 64, fibre Bragg gratings 62, and couplers 65 which connect to the pump modules 59 via optical fibres 66. The couplers 65 can be based on multimode couplers, fused couplers, V-grooves, or coupling schemes for cladding pumping an optical fibre. The fibre pump laser 61 is coupled to the optical fibre 4 via an optical fibre 68 and splices 67. The fibre pump laser 64 can be a multimode laser. Alternatively, the fibre pump laser 64 can be a single mode laser which is advantageous for core-pumping the optical fibre 4. Core-pumping allows the optical fibre 4 to be much shorter than a cladding pumped laser. This is advantageous for the reduction of non-linear effects (such as Raman and Brillouin scattering) and for the realisation of short pulses in Q-switched lasers and master oscillator power amplifiers. The optical fibre 4 can be doped with erbium and pumped at 1530nm. The fibre pump laser 64 can be doped with erbium, erbium ytterbium, or ytterbium, and either pumped at around 980nm (or 915nm if ytterbium is present), or pumped at 1480nm.

Figures 7 to 9 show examples of the optical fibre 4. Figure 7 is a double clad fibre having a core 71, a first cladding 72 and a second cladding 73. The first cladding 72 is non-circular containing a flat surface 74 to assist mode coupling. Figure 8 shows another example of a double clad fibre whose first cladding 72 is rectangular. The refractive index of the core 71 is greater than the refractive index of

the first cladding 72, which is greater than the refractive index of the second cladding 73. Optical radiation from pump diodes is typically coupled to the first cladding 72. The rare earth dopant 5 is located in at least one of the core 71 and the first cladding 72. Alternatively, as shown in Figure 9, the rare earth dopant 5 may be located in a ring 92 around the centre of the core 71. The ring 92 may be in the core 71, in the first cladding 72, or in both the core 71 and the first cladding 72. The first and second claddings 72, 73 may each be a glass or a polymer. Typically, the first cladding is silica and the second cladding is a high temperature polymer.

Figure 10 shows an optical fibre 4 having first and second claddings 72, 73 that contain longitudinally extending holes 102, 103, and a guidance region 101. The guidance region 101 may contain rare earth dopant 5. The guidance region 101 can be doped or undoped, and can have a refractive index that is equal to or greater than the refractive index of the first and second claddings 72, 73.

Figure 11 shows an apparatus in which the pump modules 59 pump an optical fibre 4 in the form of a Q-switched laser whose optical radiation 6 is coupled to the scanner 56. The apparatus comprises a modulator 111 in the form of an optical switch operating as a Q-switch. The Q-switch controller 112 is controlled in synchronism with the scanner 56 by means of the controller 113. The controller 113 may be computer controlled. The apparatus is useful for materials processing applications with short (10 to 50ns) high-energy (0.1mJ to 1mJ) pulses at eye safe wavelengths, and with the low thermal heat generation advantages that can be achieved with in-band pumping.

Figure 12 shows an apparatus that comprises modulators 121 in the form of pump diode current modulators. The modulators 121 modulate the power from the

pump modules 59. The modulators 121 are operated in synchronism with the scanner 56.

Figure 13 shows apparatus that comprises a seed laser 131, the apparatus being in the form of a master oscillator power amplifier. The optical fibre 4 operates as an amplifier, there being no reflectors to form a laser cavity. The seed laser 131 may be a semiconductor laser diode. The apparatus may include a control circuit 132 to shape the optical radiation 6 to a desired temporal characteristic 133 such as a waveform with substantially rectangular pulses. The apparatus may include a detector (not shown) to feedback the shape of the optical radiation 6 to the control circuit 132.

The apparatus shown with reference to Figures 1, 4, 5, 6, 11, 12 and 13 have all been shown with single stage lasers and amplifiers. To achieve sufficient energy in the pulses it is more common to use multistage amplifiers which can be separated with isolators. In addition, one or more feature from any of the embodiments may be used in other embodiments. In particular, the fibre pump laser 64 may be used as a pump in the other embodiments.

It is to be appreciated that the embodiments of the invention described above with reference to the accompanying drawings have been given by way of example only and that modifications and additional components may be provided to enhance performance.

The present invention extends to the above-mentioned features taken in isolation or in any combination.

Claims

1. Apparatus for material processing which apparatus comprises a pump for providing pump radiation at a pump wavelength, and an optical fibre doped with rare earth dopant, CHARACTERISED IN THAT the rare earth dopant emits optical radiation at a signal wavelength in excess of 1400nm when pumped by the pump radiation.
2. Apparatus according to claim 1 in which the pump radiation in-band pumps the rare earth dopant.
3. Apparatus according to claim 1 or claim 2 in which both the pump wavelength and the signal wavelength are between 1500nm and 2500nm.
4. Apparatus according to any one of the preceding claims in which the pump comprises a broad stripe laser diode.
5. Apparatus according to claim 4 in which the broad stripe laser diode is optically coupled to the optical fibre.
6. Apparatus according to claim 4 in which the broad stripe laser diode pumps a laser.
7. Apparatus according to claim 6 in which the laser is a fibre pump laser.
8. Apparatus according to claim 7 in which the fibre pump laser is a single mode laser.
9. Apparatus according to claim 7 in which the fibre pump laser is a multi mode laser.
10. Apparatus according to any one of the preceding claims in which the apparatus comprises a pump fibre connecting the pump to the optical fibre.
11. Apparatus according to claim 10 in which the pump is located remotely from the optical fibre.

12. Apparatus according to any one of the preceding claims in which the rare earth dopant is selected from the group comprising erbium, holmium and thulium.

13. Apparatus according to claim 12 in which the rare earth dopant is co-doped with ytterbium.

14. Apparatus according to claim 12 or claim 13 in which the rare-earth dopant is pumped substantially at the peak of its absorption band.

15. Apparatus according to any one of the preceding claims in which the optical fibre includes a core, and in which the pump radiation is coupled to the core.

16. Apparatus according to any one of claims 1 to 14 in which the optical fibre comprises a core, a first cladding and a second cladding, the refractive index of the core is greater than the refractive index of the first cladding, the refractive index of the first cladding is greater than the refractive index of the second cladding, and in which the pump radiation is coupled to the first cladding.

17. Apparatus according to claim 16 in which the rare earth dopant is located in at least one of the core and the first cladding.

18. Apparatus according to claim 17 in which the rare earth dopant is located in a ring around the centre of the core.

19. Apparatus according to any one of claims 16 to 18 in which the second cladding comprises a glass.

20. Apparatus according to any one of claims 16 to 18 in which the second cladding comprises a polymer.

21. Apparatus according to any one of claims 16 to 20 in which the second cladding is solid.

22. Apparatus according to any one of claims 16 to 20 in which the second cladding contains longitudinally extending holes.

23. Apparatus according to any one of claims 16 to 22 in which the first cladding is solid.

24. Apparatus according to any one of claims 16 to 22 in which the first cladding comprises longitudinally extending holes.

25. Apparatus for material processing comprising at least one laser diode for providing pump radiation at a pump wavelength, an optical fibre having a core, a first cladding and a second cladding, which optical fibre is doped with rare earth dopant which when pumped at the pump wavelength emits optical radiation at a wavelength in excess of 1400nm, CHARACTERISED IN THAT the pump wavelength is selected to in-band pump the rare-earth dopant, the laser diode is a broad stripe laser diode, and the pump radiation is coupled into the inner cladding.

26. Apparatus according to any one of the preceding claims in which the optical radiation is coupled to a scanner.

27. Apparatus according to any one of the preceding claims in which the apparatus includes a modulator.

28. Apparatus according to claim 27 in which the modulator is an optical switch.

29. Apparatus according to claim 27 in which the modulator controls the output power from the pump.

30. Apparatus according to claim 26 and including a controller and a modulator, in which the modulator modulates the optical radiation from the optical fibre, and the controller controls the modulation in synchronism with the scanner.

31. Apparatus according to any one of the preceding claims, the apparatus being in the form of a Q-switched laser.

32. Apparatus according to any one of claims 1 to 30 and including a seed laser, the apparatus being in the form of a master oscillator power amplifier.

33. Apparatus according to claim 32 and including a control circuit to shape the optical radiation to a desired temporal characteristic.

34. Apparatus substantially as herein described with reference to the accompanying drawings.

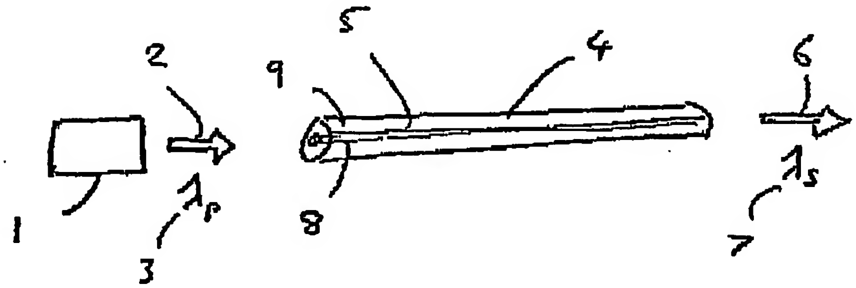


FIG 1

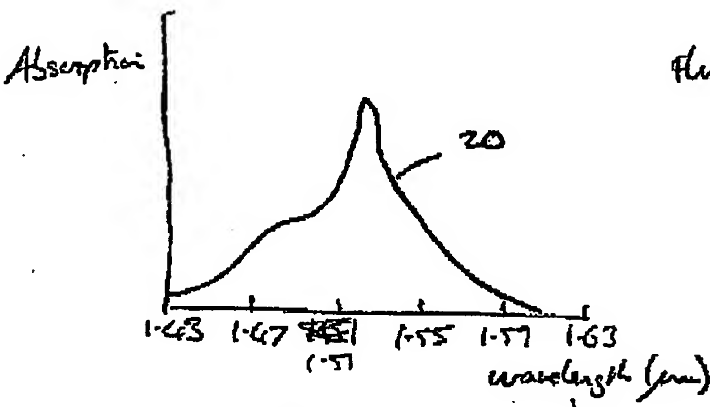


FIG 2

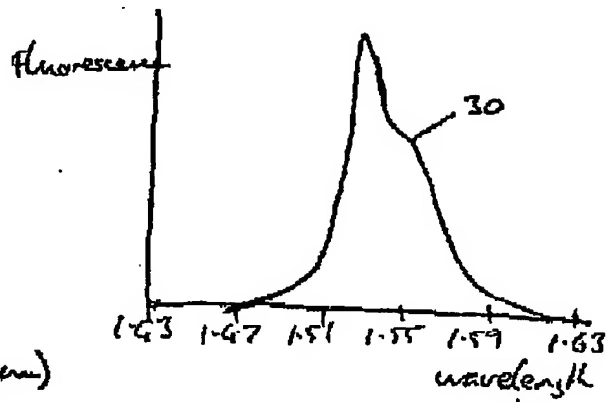


FIG 3

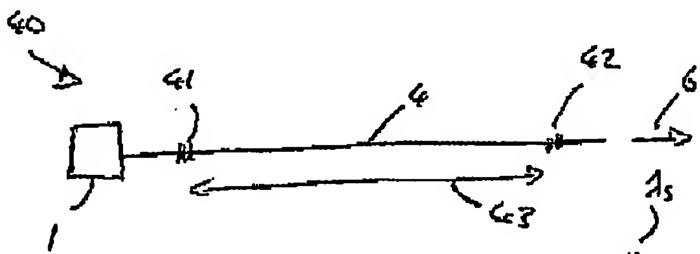


FIG 4

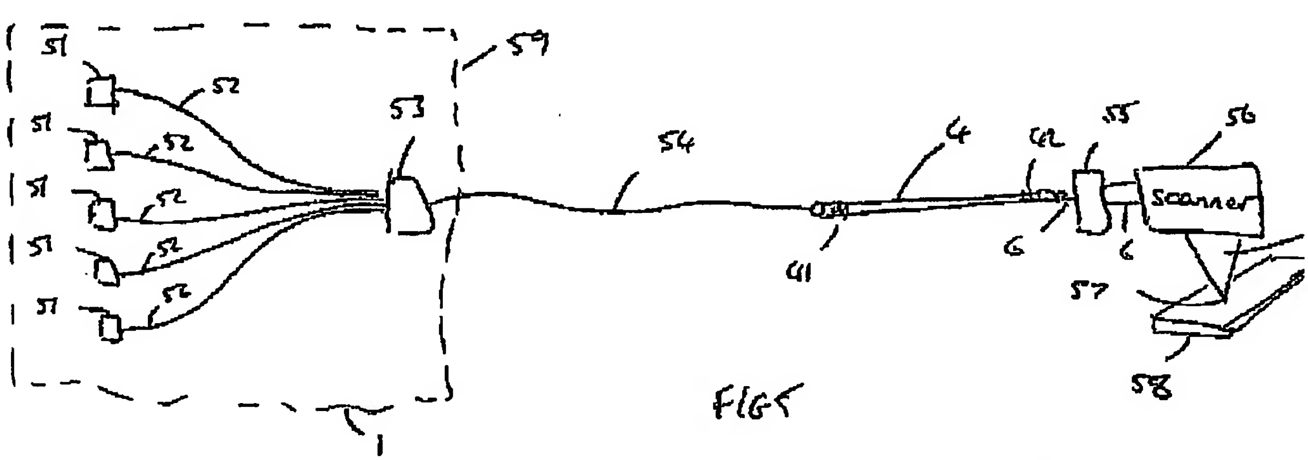


FIG 5

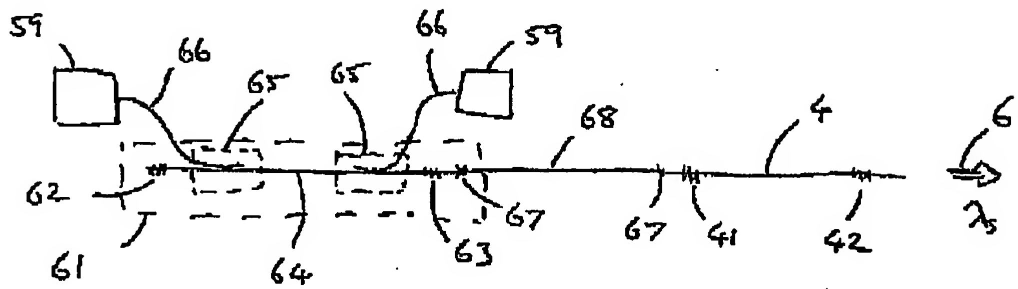


FIG 6

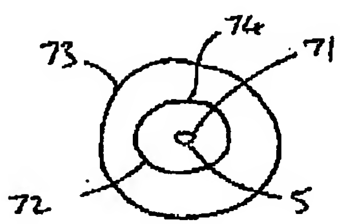


FIG 7

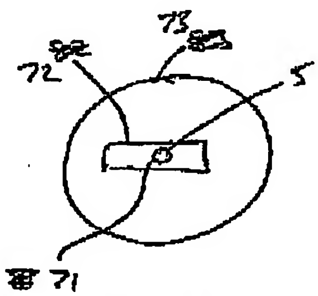


FIG 8

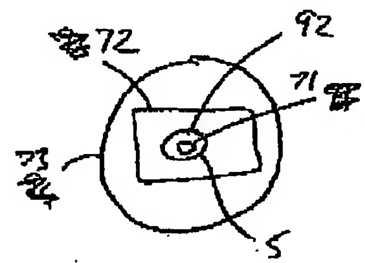


FIG 9

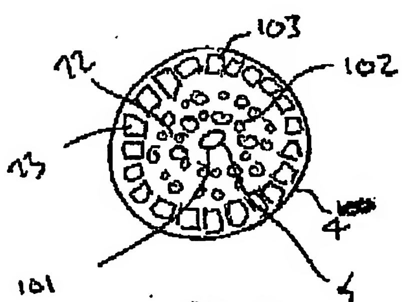
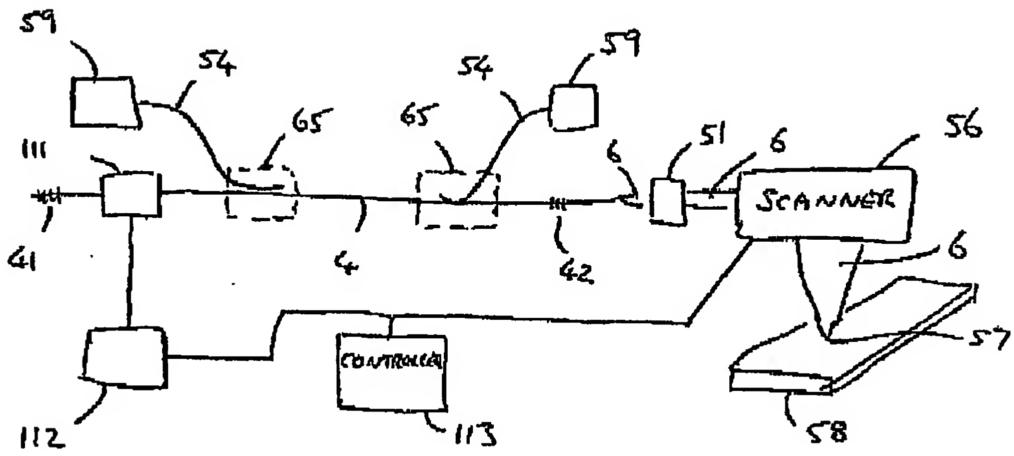


FIG 10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CONTROLLER
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113
58

FIG 11

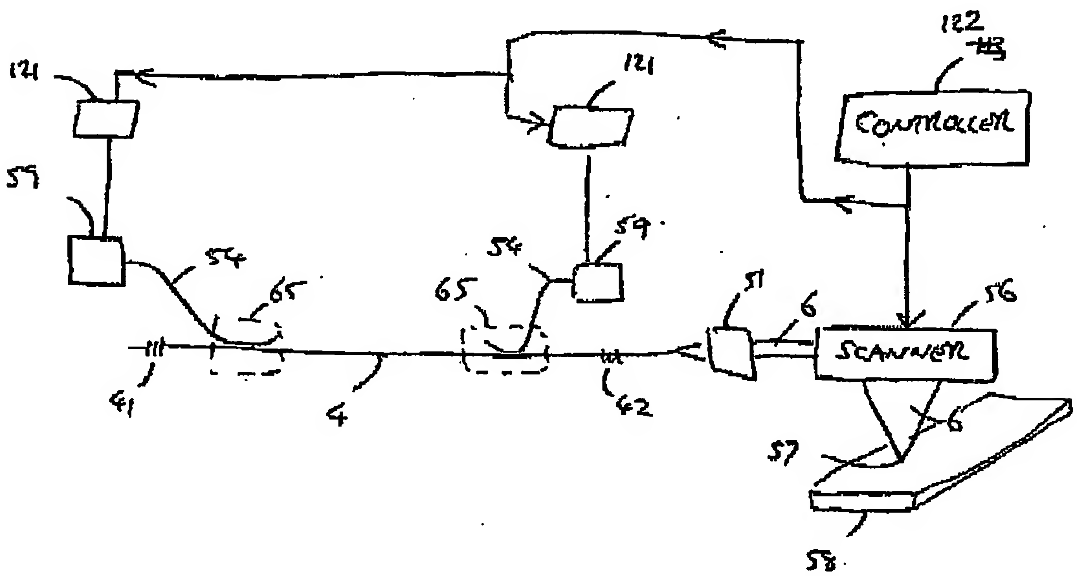
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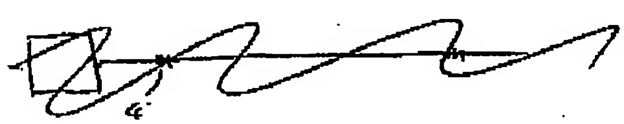
FIG 12



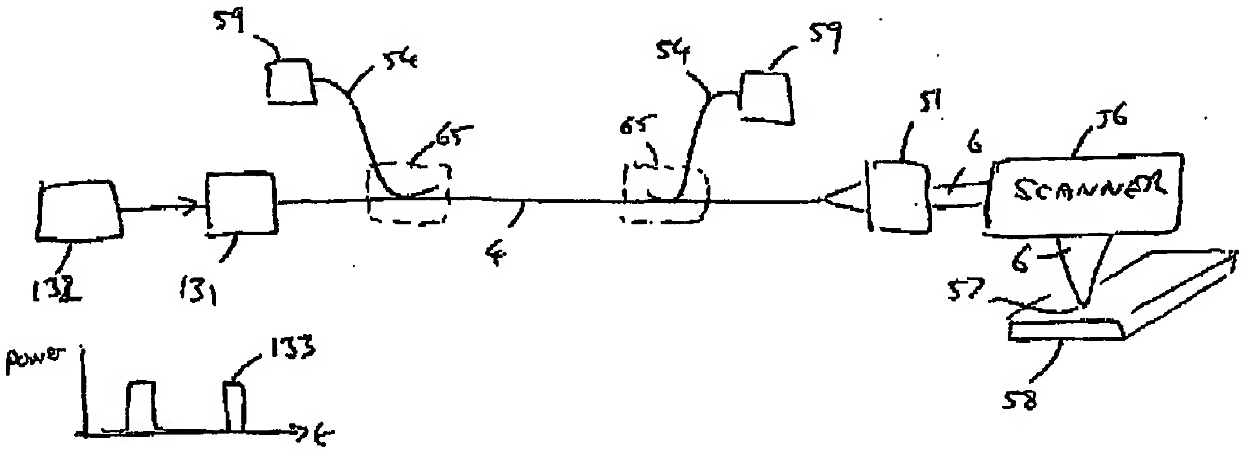


FIG 13